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WHEAT INVESTIGATIONS. I. PURE LINES

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BULLETIN 285

WHEAT INVESTIGATIONS. I. PURE LINES.[1]

By Jacob Zinn.

SUMMARY

The present bulletin contains an account of the origin and development of a number of pure lines of wheat by the method of selection, including data on all the important stages, except milling, from the single head selection to the bakehouse. The study of the effect of the environment of Northern Maine upon the physical and chemical characteristics of pure strains introduced from Minnesota forms an incidental feature of this report.

In 1915 several hundred wheat spikes were selected from commercial varieties representing the chief groups of hard red spring wheat. Of these selections 259 heads were retained and each grown in a row in the cereal crop nursery in 1916. In the following year 91 strains of the original selections were grown in one two-thousandth acre plots, along with 7 pure strains introduced from Minnesota. The crop from the one two-thousandth acre plots furnished enough seed to make a chemical determination of the crude protein content of each strain. In 1918 only 44 pure lines selected from Aroostook wheats and 6 lines of Minnesota wheats were retained and grown in plots ranging from one two-hundredth to one-fortieth acre in area. A complete chemical analysis of the wheat and flour of 37 lines and a baking test of 31 lines were made in the spring of 1919.

Under the same conditions of environment the pure lines of wheat showed distinct differences in the physical and chemical characteristics and in the bread making value of their grain.

The average weight per 1000 kernels for all lines was found to be 35.314 grams. The individual strains within a variety showed a very considerable variation in the weight per 1000

[1]Papers from the Biological Laboratory of the Maine Agricultural Experiment Station, No. 132.

kernels—ranging from 26.541 to 44.789 grams—as well as a marked deviation from the average of their respective parent varieties. The strains with the highest weight per 1000 kernels produced the greatest percentage of yellow berries and yielded flours of poor baking quality. The environmental conditions prevailing in Aroostook brought the low kernel weight of the original Minnesota seed up to the level of the Aroostook strains within a single season. This change, however, was not found to be progressive.

The data on the yield, though very limited, show a number of strains of high yielding capacity. Each variety furnished high and low yielding strains the differences in yield between the lines of the same variety being greater than between varieties.

The average protein content of the Aroostook lines was 13.81 and 12.62 per cent for the season of 1917 and 1918, respectively. The Canada Red (Ladoga type) and Preston strains yielded the highest, the Marquis the lowest protein content.

A study of the relationship between the protein content of the pure lines in 1917 and 1918 revealed a tendency for the varieties as well as for the strains to retain their relative rank with respect to protein content from one year to the next. The coefficient of correlation between the protein content of the pure strains in 1917 and 1918 was found to be $0.381 \pm .092$.

Certain strains of bread wheats introduced from Minnesota retained their high protein content under Aroostook conditions. The average protein content of the Aroostook grown Minnesota bread wheats was somewhat higher than that of the Aroostook pure lines for two successive seasons. The durum strains, however, showed a very rapid deterioration. The Minnesota grown durum strain, Speltz Marz, headed the list of the Minnesota introductions in regard to protein content; at the end of a single season's growth in Aroostook this line showed the second lowest protein content of all 99 strains analysed. The second durum strain, Hedge Row, showed the lowest protein content of all lines at the end of the first season under Aroostoook conditions. The low protein content was accompanied by the production of a very high percentage of yellow berries.

A number of the pure lines showed a high gluten content, the Preston strains ranking highest being followed by the Minnesota, Red Fife, Canada Red, Bluestem, and Marquis lines in

the order named. The Red Fife and Bluestem furnished a number of strains with good quality glutens while the Preston and Marquis yielded a large percentage of strains with fair to poor quality of gluten. The Minnesota lines, with the exception of the durum and Marquis wheat yielded a strong elastic gluten of good quality.

The baking test showed very marked variations in the flour strength of the different pure lines, the volume of bread loaf, baked from 340 grams of flour, ranging from 1518 to 2221 cubic centimeters. A number of strains produced bread possessing a good volume and very good appearance, good to very good texture and color of crumb, and excellent eating qualities. Some of the Minnesota strains produced a very good volume and showed very good baking quality.

The available data indicate that strains of wheat of good quality can be isolated and successfully grown under Aroostook conditions.

INTRODUCTION.

One of the most perplexing problems connected with agricultural crops is the quality of wheat. Though wheat has perhaps a wider range of distribution throughout the world than any other crop, yet the regions in which strong wheats of best quality are successfully grown, are very distinct and rather limited. This relation between the quality of wheat and the environment is of greatest concern primarily to the plant breeder who attempts the improvement of the strength of wheat in regions outside the natural districts of the hard red wheats. It is a well known fact that the majority of wheats grown in the forested regions of the northeast are at best semi-hard and do not come up in their bread-making quality to the high standards of the wheats grown in the prairie regions of the Northwest and Russia. As a direct effect of the influence of the environment upon the wheat grain it has been frequently observed that when some of the hard vitreous wheats from the prairie regions are introduced into localities marked by a cool summer, abundant rainfall and high relative moisture, they tend to lose their translucency and horny texture and assume a plump, dull opaque appearance.

As the baking quality or strength of wheat has been commonly regarded as being determined by the chemical composition, the problem of strength in wheat has long been studied from the chemical point of view. Two aspects of this problem were especially subjected to a frequent study, viz., the relation between the chemical composition and the bread-making value, and the influence of the environment upon the chemical composition of wheat. In the first stage of the study of the relation between the chemical composition and strength the quantity of protein and gluten was regarded as the determining factor of strength. As the accumulating evidence on this point was not concordant the investigators in this field turned to the study of the quality of gluten, notably its chemical quality. Various theories have been suggested in explanation of the strength of wheat, such as the gliadin number i. e. the ratio of gliadin to glutenin, the absolute amount of gliadin in the flour, the ratio of nitrogen to available potassium, the nitrogen in amino form, the ratio of total nitrogen to soluble nitrogen in flour, enzymic activity, etc. The study of the physical properties of the gluten gained an impetus since the work of T. B. Wood[2], who after establishing that the gliadin and glutenin of strong and weak flours were identical, found that the strength of wheat flour "is associated with a high ratio of proteid to salt and that the size of the loaf depends in the first instance on the amount of sugar contained in the flour together with that formed in the dough by diastatic action."

In studying the extensive literature on the chemistry of the strength in wheat one must be impressed with the marked divergence of views on this problem despite the careful work and standard analytical methods. In view of this the plant breeder is naturally inclined to suspect the heterogeneous nature of the material as being responsible for the conflicting results. For in the study of the chemistry of strength the individuality of the wheat variety that furnished the flour, its inherent specific influence upon the baking value, has been generally neglected. And yet it would seem more reassuring to the plant breeder if in the investigation of such a subtile problem as strength in wheat an inductive rather than deductive procedure be adopted

[2]Wood, T. B. The Chemistry of Strength of Wheat Flour. Jour. Agric. Sci. 1907 Pt. I., pp. 139-160 and II pp. 267-277.

by analyzing a given variety of wheat into its component strains and determining the behavior of the flour from each strain under identical conditions. In tracing down the specific behavior of the flour from isolated, individual strains or pure varieties certain varietal features may be established which otherwise may completely elude detection in the analysis of commercial samples of flours furnished by different wheat varieties. Whatever the cause of the discordant results, the fact remains that at the present time there is no commonly accepted, reliable chemical formula that could guide the plant breeder in detecting the strength in wheat.

The plant breeder who attempts the improvement of the wheat quality in regions outside the natural wheat lands will find still less encouragement if he turns to results and conclusions bearing on the influence of the environment upon the chemical composition of wheat. Here, again, the opinions of the workers are at variance. Without reviewing here the extensive literature relative to the question of climate and soil relations to the chemical composition it may be stated that the majority of investigators, notably Lyon[3], Thatcher[4], Le Clerc and Leavitt[5], Shaw and Walters[6], Le Clerc and Yoder[7], consider the climate as the predominating factor controlling the chemical composition of wheat to the negligence or even exclusion of the soil factors. As an interesting event in this connection it may be noted that the agronomic workers who met in the third western agronomic conference at Cornwallis, Oreg. 1918, agreed that quality of wheat was dependent on both soil and climatic conditions.[8]

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[3]Lyon, T. L. Improving the Quality of Wheat. U. S. D. Agr. Bur. Plant Ind. 1905 Bull. 78, pp. 1-120.

[4]Thatcher, R. W. The Chemical Composition of Wheat. Wash. Agr. Exp. Sta. Bull. No. 111, pp. 1-79, 1913.

[5]Le Clerc, J. A. and Sherman Leavitt. Tri-local Experiments on the Influence of Environment on the Composition of Wheat, 1910. U. S. Dept. Agr. Bur. Chem. Bull. 128 pp. 1-18.

[6]Shaw, C. W. and Walters, E. H. A Progress Report Upon Soil and Climatic Factors Influencing the Composition of Wheat. Cal. Agric. Exp. Sta. Bull. 216. pp. 549-574, 1911.

[7]Le Clerc, J. A. and Yoder, P. A. Environmental Influences on the Physical and Chemical Characteristics of Wheat. 1914. Jour. Agr. Res. V. I, No. 4, pp. 275-291.

[8]Jour. Am. Soc. Agr. V. 10, No. 7-8, 1918, p. 312.

As in the study of the relation of chemical composition to quality so also in most of the investigations into the effect of environment upon chemical composition very little significance was attached to the seed as a factor influencing the composition of the crop. The conclusions reached in these investigations are well reflected in Le Clerc's statement that "soil and seed play a relatively small part in influencing the composition of crops." (L.c. 1910 p. 18), and that "environment rather than what has been usually termed heredity is the major factor in determining the physical and chemical characteristics of the wheat crop." (L.c. 1914, p. 291).

In view of the generally accepted relation between the chemical composition and quality of wheat these results may become of some concern to the plant breeder. However, in this and similar work again the conclusions are based on the evidence obtained from samples of commercial varieties of wheat. The few experiments with pure strains of wheat entering into this work were concerned with the cumulative effect of selection rather than with the selection and retention of prepotent strains. A common feature of most of the older publications on the influence of environment upon the chemical composition is that they are not accompanied by baking tests, hence do not bear directly on the quality of wheat.

With the advent of the modern principles of plant breeding a third factor, namely, the inherent characteristics of the different varieties and strains, entered into the consideration of causes influencing the quality of wheat. The first important question confronting the plant breeder was, whether the quality of wheat was merely a function of the environment indiscriminately levelling it regardless of the individual characteristics of the different varieties or strains. Biffen[9] first subjected the physical characters associated with strength to a genetic analysis and found that "strength" and "weakness" form a pair of Mendelian characters. Upon these theoretical results a number of hard, crossbred strains have been built up and tested in the bakehouse. The practical significance of the application of modern breeding principles in the improvement of the quality of wheat is further illustrated by the experiments of the Home Grown Committee

[9]Biffen, R. H. On the Inheritance of Strength in Wheat. Jour. Agr. Sci. 1908. V. III pp. 86-101.

of the National Association of British and Irish Millers[10] which demonstrated that a number of varieties, notably the Red Fife selections retain their original strength under all conditions when other varieties change enormously with climate and soil. Similar results were obtained by Howard, Leake and Howard[11] in India who found that among 25 pure line cultures representing as many distinct wheats, when grown under different conditions at three stations, some strains always remained soft, some had a tendency to remain hard while with the majority of these strains the consistancy varied greatly according to the locality and the conditions under which they are grown (L.c. p. 59). Four strong wheats and one soft strain were each grown at 9 different stations under widely varying conditions of climate, soil and culture. The 4 strains consistently retained their strength and milling qualities while the soft strain always remained a weak wheat.

As a further illustration of the effectiveness of the application of modern plant breeding methods in the improvement of wheat quality the results at the Central Experimental Farm at Ottawa, Ontario, those of Farrer in New South Wales, of Clark [12] and of Leith[13] should be cited.

The results of a recent investigation of Freeman[14] are of special interest in their bearing upon the influence of environment upon the texture of the wheat kernel. In his experiments involving crosses between soft wheats and durum, Freeman established two types of soft grains. One type was designated by him as "true softness" in which the air spaces in the endosperm are diffuse and finely scattered. This type of softness is only slightly affected by environic conditions. The second type, commonly called "yellow berry" was characterized by air spaces

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[10]Humphries, A. E. and Biffen, R. H. The Improvement of English Wheat. Jour. Agr. Sci. 1917, V. 2, pp. 1-16.

[11]Howard, Albert, Leake, H. M. and Howard, G. L. C. The Influence of the Environment on the Milling and Baking Qualities of Wheat in India. Memoirs Dept. Agr. India 1913. Vol. V. No. 2, pp. 45-102.

[12]Clark, J. A. Improvement of Ghirka Spring Wheat in Yield and Quality. 1916. U. S. Dept. Agric. Bu. Plant. Ind. Bull. 450, pp. 1-19.

[13]Leith, B. D. The milling and Baking Qualities of Wisconsin Grown Wheats. Wisc. Agr. Exp. Sta. Res. Bull. 43, 1919. pp. 1-38.

[14]Freeman, Geo. F. Producing Bread Making Wheats for Warm Climates. Jour. Heredity, 1918, V. 9, No. 5, pp. 211-226.

within the endosperm occurring in flakelike groups with quite definite margins, causing a more or less extending opaqueness. This type was found to be very sensitive to environic conditions. Both types were found to exhibit a distinctly different genetic behavior controlled by different sets of genetic factors. The practical importance of these results is apparent for they draw a distinct line between true soft wheats like Sonora, Early Bart which are not affected by climate and are every year 100% soft, and the hard wheats whose response to environmental influences manifests itself in a greater or less percentage of "yellow berries."

The present paper deals with the results obtained in the work with a number of pure lines of wheat originated and grown at the Aroostook Farm of the Maine Agricultural Experiment Station. The main object of this work was to attempt to improve the strength of the Aroostook wheats, and this bulletin may be regarded in a way as a progress report on that phase of this work based on the method of pure line selection. In presenting the results of the chemical analyses the writer wishes to emphasize the fact that these data reflecting as they do the chemical composition and behavior of the wheats and flours, all refer to pure strains of wheat in distinction to commercial varieties and flours. Some observations on the effect of the environmental conditions of Northern Maine upon a few pure strains of wheat introduced from Minnesota are also here reported.

CLIMATE AND SOIL RELATIONS IN AROOSTOOK COUNTY.

As already stated the growing of wheat in Maine is confined to its northern section made up chiefly of Aroostook County. In view of the exceptional significance commonly attached to the environment in relation to the quality of wheat, a brief consideration of the climatic and soil factors of Northern Maine appears desirable.

Northern Maine is characterized by a cool, and moist climate and a short growing season. The mean temperature, the rainfall, and the number of clear days for the five months in each of the last 7 seasons, 1913-1919, are given in Table 1.

The outstanding feature in this table is the high precipitation during the growing season. Reference to the data on cli-

matic conditions given by Carlton[15] for the principal wheat growing centres in Russia and in the United States shows that the total precipitation for the growing season at Presque Isle—16.05 inches—is considerably higher than at the principal wheat growing points of the Russian prairies and generally higher than at points in the Great Plains. While this alone would not constitute a specially detrimental feature in connection with the cultivation of wheat, a consideration of the peculiarities of the Aroostook growing season indicates that the distribution of the rainfall in the different months of the season may have some effect upon the quality of Aroostook grown wheat. The time of seeding small grains in Aroostook County extends usually

TABLE 1.

Temperature, Rainfall in Inches and Number of Clear Days for the 5 Growing Months of the Seasons 1913-1919. Recorded at Presque Isle, Aroostook County.

Month	Temperature Precipitation No. clear days	Year							Average
		1913	1914	1915	1916	1917	1918	1919	
May	Mean Temp.	48.60	53.19	49.50	50.82	43.13	51.00	50.50	49.46
	Precipitation	3.53	2.74	4.05	3.45	3.90	4.00	3.32	3.57
	No. clear days	15	18	10	12	8	17	11	13
June	Mean Temp.		56.03	60.60	59.65	59.84			59.03
	Precipitation	1.20	4.80	1.95	2.17	7.67		1.26	3.18
	No. clear days	18	12	12	10	10		15	13
July	Mean Temp.	69.30	63.55	64.10	65.00	67.95			65.98
	Precipitation	5.18	2.23	3.40	3.68	2.56		3.80	3.48
	No. clear days	9	24	18	17	15		14	16
August	Mean Temp.	61.40	60.17	61.80	71.90	66.90		61.00	63.86
	Precipitation	3.01	2.35	3.50	1.70	5.30		1.75	2.94
	No. clear days	20	22	15	11	18		11	16
September	Mean Temp.	53.20	55.80	56.45	58.92	53.05		53.60	55.17
	Precipitation	2.01	2.10	3.25	4.05	1.41		4.56	2.90
	No. clear days	19	19	19	15	19		13	17
Totals for growing season:									
Total Precipitation		14.93	14.22	16.15	15.05	20.84		14.69	16.05
Total No. clear days		81	95	74	65	70		64	75
Average mean temperature of growing season		58.10	57.75	58.49	61.26	58.18		55.00	58.70

[15]Carlton, M. A. The Small Grains, 1916, pp. 699. The MacMillan Co., New York.

from the 8-20 of May. Owing to the cool, moist conditions in Aroostook the vegetative period of wheat is rather extended and the flowering which begins about the middle of July continues to about the end of July. August is the ripening month, the wheat being harvested in the last week of August or the first week of September. Referring to the figures in the last column of Table 1 it will be seen that the highest precipitations occur in May, 3.57 inches, but that the rainfall during the period of ripening and harvest—August,—is only slightly over half an inch or 18 per cent less than the maximum monthly rainfall for the season. Rainy weather during the period of ripening and harvest not only may have a detrimental effect upon the appearance of grain but is associated with another feature of climate, namely humidity which is known to have a distinct effect upon the quality of wheat. High relative humidity associated with an overcast sky characterizes the weather in Aroostook County towards the end of July and the first week of August which period marks the first stages of the kernel formation. This feature is rather unfortunate as dry weather and a clear sky during the process of ripening are very essential to the production of a strong, high grade wheat. This humid condition protracts the ripening period and delays the harvest. The lengthened ripening period extending through August results in a further drawback as the formation of the wheat kernel does not coincide under Aroostook conditions with the highest seasonal temperature, which marks the month of July. While from the seven year average given in Table 1 it appears that the mean temperature in August is only 2 degrees lower than in July, the actual difference is much greater since the amount of sunlight and heat decreases in the shortening days of August. Medium late wheat varieties when planted in the latter part of May often do not mature until the first week of September when frequently the first early frosts occur.

While these are the natural limitations relative to the growing of strong wheat in Aroostook, it must be admitted that the climatic conditions prevailing there are favorable in regard to other features of the wheat crop. Thus the wheat crop is practically free from insect pests, and is seldom affected with stem rust.

SOILS.

The soils of Aroostook County have been formed by glacial drift, and vary from sand to heavy silt loams. According to Westover and Rowe[16] there are twelve distinct soil types in Aroostook County, but the greater part of the area is made up of a friable loam, Caribou loam, derived from unmodified glacial drift. The Caribou loam is composed of about 50% silt and only 16% of clay, the rest being made up of more or less fine sand and gravel. The soil though most ideal for the potato crop, is well adapted to small grains. The average yield of wheat is about 25 bushels per acre. The fertility of the soil is kept up by high applications of commercial fertilizers in connection with the potato crop, very little barnyard manure being used. The humus content of Aroostook soils is restored through cultural methods which consist of a crop rotation usually including potatoes one year, grain one year and clover and timothy for two or three years. Frequently, however, this rotation is not adhered to potatoes being grown for two or more years in succession. In such cases the drain upon the humus of the soil is probably too great to insure good wheat crops following the potatoes.

CHARACTERISTICS OF THE AROOSTOOK GROWN WHEATS.

The commercial wheat varieties grown in Aroostook are classed with the semi-hard spring wheats of the Northeastern wheat district. The varieties of wheat grown at present in Aroostook belong to two spring wheat groups—Fife and Preston. Owing to the prejudice of some growers against the awned wheat, the majority of the Aroostook wheat varieties belong to the beardless Fife group. More recently the Marquis wheat has found its way from the Northwest into Aroostook County, but does not seem to be so well adapted as the Fife wheats.

An investigation into the physical characteristics and chemical composition of Aroostook grown wheats and into their mill-

[16]H. L. Westover and R. W. Rowe. Soil Survey of the Caribou Area, Maine, U. S. Dept. Agr. Bur. of Soils, 1910, pp. 1-40.

ing and baking value was made by Woods and Merrill[17]. An especially interesting feature of their investigation in its bearing upon the observations reported in the present paper is their study on the effect of the climate upon the physical appearance and chemical composition of wheats imported from the Northwest and grown in Aroostook. They found that the wheat varities introduced from the Northwest changed their physical and chemical character at the end of a single season, the change being most pronounced in the increased size of the kernel. Relative to the effect of Aroostook environmental conditions upon the protein content of Northwestern wheats the evidence from the trials of Woods and Merrill is inconclusive. In the first experiment one of the three varieties tested, Lamona wheat, suffered at the end of the first season under Aroostook conditions a large loss of nitrogen and a still larger loss in the gluten content, while the Fife wheat showed only a small decrease in gluten and the Bluestem wheat made a slight gain in protein, both these varieties gaining in gluten. The results from the second experiment in which two pure strains of Minnesota bred Bluestem and one commercial variety of Bluestem were used, showed a decrease in protein content for the commercial variety and for one of the pure strains as compared with the Minnesota grown parents, but on the following year all three varieties showed a higher percentage of protein in the Aroostook grown progeny than in the check trials of the Minnesota grown progeny.

As to the baking quality of the Aroostook grown wheats the baking tests reported by Woods and Merrill show that the flour from Maine wheats produced as a rule loaves of smaller volume than the Minnesota standard flour, though of good quality. The writers noting the arbitrary nature of the northwestern standard, suggest that Maine develop the growing and milling of wheat along its own lines, and express the belief that "by careful breeding from wheat now being grown in Maine it would be possible to develop a strain equal for Maine conditions to some of the improved strains of other sections."

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[17]Chas. D. Woods and L. H. Merrill. Notes and Experiments upon the Wheats and Flours of Aroostook County. Maine Agr. Expt. Sta. Ann. Rept. 1903, pp. 145-180. (Bull. No. 97).

MATERIAL AND METHODS.

In undertaking the wheat improvement work at Aroostook Farm in 1915 the question arose as to what material should be used as the source of improved wheat strains. A consideration of the deterioration in the physical characteristics of the northwestern wheats under Aroostook conditions, and of the great differences between the environment of Maine and the Northwest, at once suggested the advisability of confining the selection work chiefly to the native Aroostook grown wheats or adjoining regions. Since the quality of the wheat crop appears quite susceptible to the influence of climatic factors it was thought that the reaction, if any, of the different varieties and strains in the course of many seasons to the environmental factors has long become established in the form of a greater or less degree of adaptation. Selection work on these varieties would result in the isolation of the best adapted varieties or strains and in the elimination of the poorly adapted ones, the degree of adaptation being measured by the maximum quality of any given strain.

The methods used in the wheat improvement work at Aroostook are based on the principles of pure line selection and hybridization. The present paper deals only with the results of the selection work. For a detailed account of the method of pure line selection and of the field technic as applied to small grains by this Station the reader may be referred to a previous paper.[18] We may only consider here a few features not mentioned in the paper just cited, which are peculiar to wheat. In selecting wheat strains for quality a certain procedure of diagnostic value is required by means of which the relative quality of the different individual plants may be determined. The yield of grain from a single spike is obviously too small to be used for a nitrogen analysis or even for a gluten determination by the chewing test without interfering with the propagation of the seed. The estimation of the quality of the grain from the individual spikes following their isolation from commercial varieties was based in this work upon the hardness, color, size and

[18]Frank M. Surface and Jacob Zinn. Studies on Oat Breeding IV. Pure Line Varieties. Maine Agric. Exp. Station, Ann. Rept. 1916, pp. 97-148 (Bulletin No. 250).

texture of the kernel. While it is recognized that these features are not always a reliable index of the quality of wheat, especially when estimating grains from different varieties, yet the diagnostic value of these determinations is enhanced when they are made upon different strains within the same variety. The determination of the physical characters of a number of strains within the same variety soon leads to the formation of a standard for each variety so that the relative quality of the kernels from the strains of the same variety can be fairly accurately judged. It may be added in this connection that the determination of the characters of the grain at the early stage of selection is really of no great importance since it is the progeny of the selected plants, the first generation after selection, that offers a more reliable basis for the determination of quality.

BRIEF ACCOUNT OF THE ORIGIN OF THE PURE LINES OF WHEAT AT AROOSTOOK FARM.

In 1915 several hundred selections were made from commercial varieties of wheat grown at Aroostook Farm and from a number of wheat fields in the County. In this work normal, medium sized spikes well developed at the tip, were selected rather than whole plants since in the close field stand it is not always possible with certainty to isolate individual plants. In these selections were represented wheat spikes of the four groups of spring wheat: Fife, Bluestem, Preston and Durum. Representative spikes and grain of these wheats are shown in Figures 1 to 6. Of these selections 259 spikes were retained and planted in rows in the cereal crop nursery in 1916. Each row was planted with the seed of a single wheat spike. The number of rows grown in 1916, each representing a strain selected from the different varieties is given on page 17.

During the growing season notes were taken on the characters of the spikes, tillering capacity, strength of straw, susceptibility to disease as well as data relative to time of heading and bloom. The data on the physical characters of the grain in conjunction with the field notes served as a basis for further selection as a result of which 91 strains of the original 259 were retained. These 91 strains were planted in 1917 in one two-thousandth acre plots. Along with the pure lines of Aroostook

FIGURE 1.

FIGURE 2.

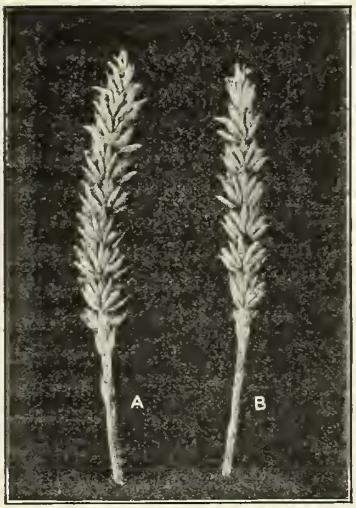

FIGURE 3.

FIGURE 4.

FIG. 1.—Representing heads of two groups of spring wheat: A, Red Fife (Line No. 2393); B, Bluestem (Line No. 2387).

FIG. 2.—Heads representing two spring wheat varieties: A, Marquis (Line No. 2398); B, Preston (Line No. 2388).

FIG. 3.—A, Royalton Red, Accession No. 186; B, Royalton White, Accession No. 185.

FIG. 4.—Head of Durum wheat (Speltz Marz, Accession No. 182.)

Variety	No. of Garden Rows in 1916	No. of Strains Continued in 1917
Red Fife	41	15
Preston	37	17
Bluestem	25	20
Marquis	49	12
Canada Red*	32	19
Unnamed	70	8
Durum	5	—
Total	259	91

grown wheats there were also tested in one two-thousandth acre plots 7 pure strains of hard spring wheat which had been obtained from Minnesota in the winter of 1916. The writer wishes to express his appreciation of the courtesy of Prof. H. K. Hayes of the University of Minnesota in sending these wheats to him. The Minnesota strains included one representative of each of the following varieties: Bluestem (Haynes Bluestem), Marquis, Velvet Chaff, Royalton (Red), Royalton (White) and two representatives of durum wheat, Speltz Marz (Fig. 4) and Hedge Row. According to a written communication from Professor Hayes the Royalton wheat was originally obtained from Royalton, Minn., and its origin was possibly a natural cross. The two strains of this wheat are very distinct, one (Royalton White) possessing a smooth chaffed spike and white grain suggestive of the White Fife, while the other strain (Royalton Red) produces a red grain and a hairy chaffed spike similar to Bluestem. The spikes of these two strains are reproduced in Fig. 3. All the Minnesota strains have been given Maine accession numbers 182 to 187.

The crop from the one two-thousandth acre plots in 1917 furnished enough seed from each strain to make a chemical analysis of the crude protein content. A further scrutiny of these pure lines on the basis of the chemical analysis and the field notes resulted in the discarding of a number of strains until 44 pure lines of Aroostook wheats and 6 pure lines of

*Dr. Chas. E. Saunders, Cerealist at the Central Experimental Farm at Ottawa, informs me that the variety here listed under the name Canada Red is probably the variety called Black Sea (identical with Ladoga). It is a bearded wheat, with smooth, reddish brown chaff and producing red kernels.

Minnesota wheats were retained. These were grown in the season of 1918 in plots ranging from one two-hundredth to one-fortieth acre in area. A further selection in the fall of 1918 reduced the number of strains to 26 originally selected from Aroostook wheats and to 5 Minnesota lines. A complete chemical analysis of 37 lines and baking tests of 31 wheat lines were made in the spring of 1919. Using the baking test as the final index of strength, out of the 31 tested strains 12 Aroostook lines and 4 Minnesota lines were retained and propagated in 1919 in one-twentieth acre plots.

ANALYSIS OF DATA.

PHYSICAL CHARACTERISTICS OF THE GRAIN.

The most striking feature in the physical appearance of the grain from the Aroostook grown lines is the size and weight of the kernels. Their size is larger than that of spring wheat of the Northwest and their plump, well rounded shape, distinguishes them from the wheats of the prairie regions. The size and shape relations of the grain of the Aroostook pure lines are illustrated in Figures 5 and 6, which represent kernels of four pure lines each belonging to a distinct wheat variety. As a result of these size and shape relations the weight of the kernels is correspondingly high. In Table 2 is given the weight per 1000 kernels of each of the pure lines grown in 1918. The lines are grouped according to the variety from which they originated and their rank in respect to kernel weight.

It may be well to point out that the determination of the kernel weight based on 1000 kernels expresses very exact relations repeated determinations showing the experimental error to be either negligible or nil. Therefore, the differences in the 1000-kernel-weight of these lines are more significant than they might appear at first sight. From Table 2 it will be noted that the average weight per 1000 kernels for all lines is quite high—35.314 grams. The average weights per 1000 kernels for the varieties do not show great differences though they very well reflect varietal means around which the strains within the varieties are grouped. The individual strains show a considerable deviation from the average of the varieties from

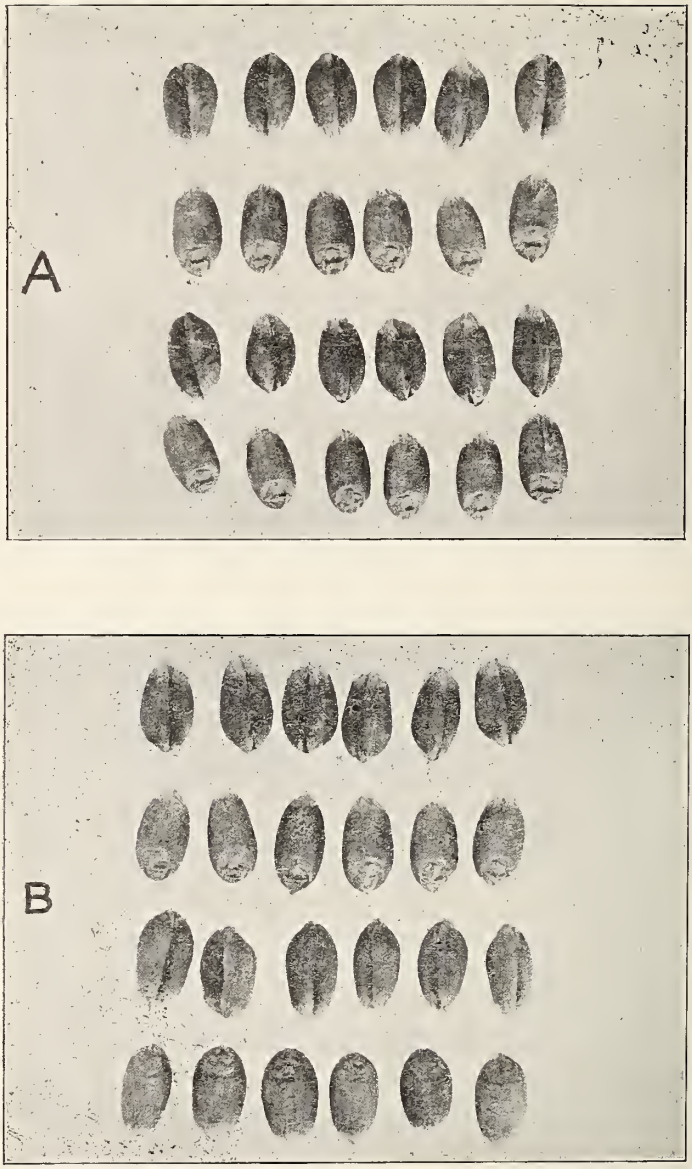

FIG. 5.—Kernels of two pure lines of wheat: A, Line No. 2389 (Red Fife); B, Line No. 2384 (Bluestem).

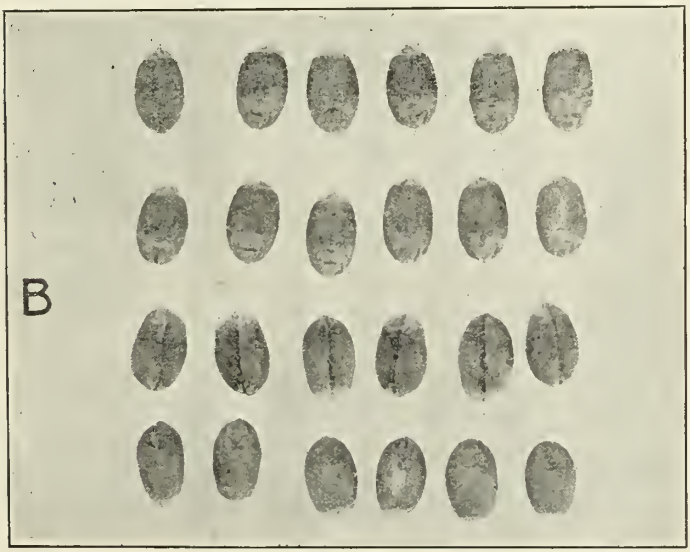

FIG. 6.—Kernels of two pure lines of wheat: A, Line No. 2388 (Preston); B, Line No. 2398 (Marquis).

TABLE 2.

Weight per 1000 Kernels of each Pure Line.

AROOSTOOK LINES

Line No.	Selected from Variety	Weight in grams
2389	Red Fife	31.180
2385	Red Fife	34.093
2379	Red Fife	34.344
2386	Red Fife	34.358
2395	Red Fife	34.536
2390	Red Fife	34.637
2393	Red Fife	34.882
Average		34.004
2394	Bluestem	34.160
2391	Bluestem	35.102
2384	Bluestem	36.043
2387	Bluestem	37.460
Average		35.691
2383	Preston	26.541
2397	Preston	30.186
2388	Preston	32.535
2414	Preston	33.556
2402	Preston	39.093
2405	Preston	43.890
2409	Preston	44.032
2400	Preston	44.789
Average		36.828
2410	Marquis	33.174
2398	Marquis	34.055
Average		33.611
2373	Canada Red	30.186
2396	Canada Red	34.498
Average		32.337
2370	Unnamed	35.942
2415	Unnamed	37.341
2406	Unnamed	37.574
Average		36.952

Average for all Aroostook lines: 35.314

which they originated as well as from the average for all lines. Thus the Preston Line 2383 has a 1000-kernel-weight over 10 grams lower than the average for the variety and over 18 grams lower than the highest weight in this variety, —44.789 grams of Line 2400. This line exceeds the average for the variety by nearly 8 grams. With the exception of Line No. 2389 the Red Fife lines show a remarkable uniformity in the 1000 kernel weight with an average below that for all lines. The Bluestem strains rank higher with an average equal to that for all lines,

while the Preston lines, with the exception of the few strains of the Unnamed variety, rank highest. The great variations in the 1000-kernel-weight of the individual strains grown in the same season on a limited, uniform piece of land, are rather noteworthy. It is further of interest to note that the lines with the very high weight per 1000 kernels as a rule yielded flour of poor baking quality. The lines that produced the largest bread volume were those with a 1000-kernel-weight not over 35 grams.

Table 3 shows the remarkable effect exerted by the Aroostook environment upon the weight of kernels of the Minnesota lines.

TABLE 3.

Showing Effect of Aroostook Growing Conditions Upon the Weight of Kernel of Pure Lines Introduced from Minnesota.

Maine Accession No.	Minnesota Accession No.	N. S. N.	Selected from Variety	Weight in grams per 1000 kernels	
				of original seed grown in Minnesota	of the same seed grown one season in Aroostook
183	1011	I-15-161	Velvet Chaff	19.786	32.891
186	1037	I-12-1	Royalton (Red)	22.000	34.315
185	1037	I-12-6	Royalton (White)	20.923	35.105
181	188x188	II-06-39	Preston x Preston	22.268	37.241
184	470	I-06-52	Hedge Row (durum)	37.411	43.104
182	337	I-00-45	Speltz Marz (durum)	37.386	45.510
Average				26.629	38.028
Average (excluding the durum lines)				21.244	34.888

The average weight per 1000 kernels of the original seed has increased by 18.7 per cent in the course of one season. It should, however, be stated that at the time of the determination of the 1000-kernel-weight the original Minnesota grown seed was older and therefore drier than the Aroostook grown seed and considerably shriveled, so that the actual difference in weight should probably be smaller. On comparing the data in Table 3 with those in Table 2 it will be seen that the average weight per 1000 kernels of the Aroostook lines is practically identical with the average weight of the Minnesota lines attained under Aroostook conditions. These data which very well agree with

the observations of Woods and Merrill[19] on 2 races of Minnesota wheat are too meager to draw from them general conclusions. The evidence obtained from the examined number of pure lines indicates that the environmental factors prevailing in Aroostook brought the kernel weight of the original Minnesota strains up to the level of the Aroostook strains very rapidly, in fact, within a single season. Further determinations made on the grain of the crop of 1918 indicate that this change in the kernel weight of the Minnesota lines is not progressive.

In regard to other physical characteristics as color, texture and hardness it was found that there was some variation among the different lines, but only of a comparatively slight nature since these characteristics were primarily used as a basis for selection. As a rule the strains with the highest weight per 1000 kernels showed the least degree of flintiness and the highest percentage of "yellow berry".

Of the Minnesota wheats 4 strains Royalton (Red), Royalton (White) Haynes Bluestem and Marquis, respectively, while suffering some loss in flintiness as compared with their original condition in Minnesota, appeared to be of good color, and texture; of the remaining three Minnesota strains the Velvet Chaff strain showed a tendency towards developing "yellow berries" while the two durum lines showed a most striking degree of deterioration. The original Minnesota sample of these lines exhibited all the characteristics of the corneous transclucent grains of the Northwestern durum wheats; after one season's growth under Aroostook conditions the already large grain gained from 6 to 8 grams per 1000 kernels and showed a very large percentage of opaque kernels of either partly or wholly starchy texture. This rapid change of the durum strains grown side by side with a number of other lines retaining their hard texture and good color furnished the best illustration of the difference in the degree of adaptation and response to the environment of the different wheat varieties. The effect of the Aroostook environment upon the size and shape of the original Minnesota seed is illustrated in Figures 7 and 8.

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[19]Loc. cit.

FIG. 7.—Showing effect of Aroostook environmental conditions upon the size and shape of wheat introduced from Minnesota: A and B, original, Minnesota grown seed (Royalton Red and Royalton White, respectively); A' and B' same seed after one esason's growth at Aroostook Farm.

FIG. 8.—Showing effect of Aroostook environmental conditions upon the size and shape of wheat introduced from Minnesota: A and B, original, Minnesota grown seed (Marquis and Durum, respectively); A′ and B′ same seed after one season's growth at Aroostook Farm.

YIELD OF THE PURE LINES IN 1918.

As already stated the pure lines were propagated in 1918 in plots ranging according to the available seed from one two-hundredth to one-fortieth acre in area. The season of 1918 was typical of Aroostook conditions, marked by heavy rain-storms which lodged some of the wheat thus offering an opportunity of

TABLE 4.

Yield and Weight per Measured Bushel of Pure Lines Grown in 1918.

AROOSTOOK LINES.

Line No.	Selected from Variety	Plot No.	Yield of Grain		Weight per measured bushel in lbs.
			Pounds per plot	Bushels per acre	
2385	Red Fife	870	5.13	51.58	60.5
2395	Red Fife	882	12.69	39.88	61.5
2393	Red Fife	880	11.44	38.62	61.3
2386	Red Fife	871	12.25	37.73	62.0
2379	Red Fife	864	4.50	33.72	
2389	Red Fife	875	10.00	33.51	61.0
2390	Red Fife	876	8.06	26.15	60.5
2387	Bluestem	873	11.88	48.00	60.0
2404	Bluestem	890	10.69	34.66	
2384	Bluestem	869	10.81	38.92	60.5
2394	Bluestem	881	11.00	34.54	60.0
2391	Bluestem	877	10.31	33.44	60.5
2382	Bluestem	867	3.00	23.93	
2402	Preston	893	3.50	53.79	
2414	Preston	910	39.75	40.04	62.5
2405	Preston	891	13.34	39.26	60.5
2400	Preston	907	40.00	34.62	62.0
2409	Preston	900	20.88	32.48	62.0
2397	Preston	884	7.75	31.79	63.3
2388	Preston	874	9.00	31.10	63.0
2381	Preston	866	4.34	29.25	
2380	Preston	865	1.65	28.62	
2383	Preston	868	5.25	25.20	61.5
2411	Preston	902	14.00	25.41	59.8
2408	Preston	894	7.13	23.71	
2398	Marquis	885	10.38	35.27	61.3
2410	Marquis	895	11.50	25.73	62.0
2378	Canada Red	909	17.00	42.74	
2375	Canada Red	904	24.00	39.35	
2376	Canada Red	905	20.00	38.54	
2374	Canada Red	901	22.75	36.47	
2372	Canada Red	898	22.00	36.68	
2371	Canada Red	896	21.75	35.73	
2373	Canada Red	899	21.50	35.04	57.5
2396	Canada Red	883	8.81	33.80	62.0
2406	Unnamed	892	13.94	44.49	57.5
2415	Unnamed	911	31.00	43.55	60.0
2370	Unnamed	862	4.75	37.54	60.5

Yield and Weight per Measured Bushel of Pure Lines Grown in 1918.—Concluded.

MINNESOTA LINES.

Maine Access. No.	Minnesota Access. No.	Selected from Variety	Plot No.	Yield of Grain		Weight per measured bushel in lbs.
				Pounds per plot	Bushels per acre	
187	1239	Marquis	888	6.56.	35.81	60.5
182	337	Speltz Marz (durum)	878	11.25	34.62	64.5
183	1011	Velvet Chaff	889	10.25	34.29	60.5
186	1037	Royalton (Red)	872	10.00	34.17	60.8
180	169	Haynes Bluestem	879	11.00	33.85	59.8
185	1037	Royalton (White)	897	13.13	32.59	60.5

judging the relative strength of straw of the different lines. The smaller plots were cut by hand with the sickle or cradle, the larger ones were reaped with the binder. The threshing was done according to the size of the plots, either with the small threshing machine used in threshing experimental plots up to one-eightieth acre in area, or with the large, farm threshing machine. The yields of 44 pure lines and the bushel weight of most of them are given in Table 4.

While relatively considered, these plots are of different size and absolutely taken, quite small, there were enough plots of approximatly the same area to give some idea of the behavior of these lines as to yield. An inspection of Table 4 will show a considerable variation in the yield of the different lines. Every variety contains strains of high and low yielding capacity. In the cases where a larger yield was obtained from an equal or smaller area the differences in yield are probably significant. Considering the larger plots in which the Canada Red strains grew, this variety furnished a number of high yielding lines. Some of the Preston lines yielded well, as did some of the Red Fife and Bluestem lines. The Minnesota lines very well approached the yielding capacity of the Aroostook lines.

From Table 4 it will be noted that these lines test rather high and that there is little variation in the bushel weight. Only two of the 44 lines tested appreciably below the standard weight, the great majority exceeding it by 0.5 to 3 pounds, and in one case (durum) by 4.5 pounds. The Preston lines stand out rather prominently with their higher bushel weight, and it is of interest

to note that line 2388 showing the highest bushel weight of all Aroostook lines furnished a flour of very good quality, best of all Preston lines. The Minnesota lines, with the exception of durum, are well grouped about the standard weight.

CHEMICAL CHARACTERS OF THE PURE LINES.

PROTEIN ANALYSIS IN 1917.

The protein content of the pure lines was first determined in 1917.* In computing the protein content from the nitrogen the factor 5.7 was used. The results of the analysis of 99 pure lines are given in Table 5. The lines are grouped within the varieties from which they originated, and according to their nitrogen rank.

An inspection of Table 5 shows a relatively high average percentage of protein for the different varieties. Certain lines within each variety group possess a protein content which under Aroostook conditions must be regarded as decidedly high. This should not surprise one if it is recalled that the lines were selected for high nitrogen as indicated by their physical characteristics. From Table 5 it will be noted that the Canada Red variety shows the highest average protein content —14.31 per cent—of all Aroostook lines. This group is followed by the Preston, Bluestem, Red Fife, Unnamed and Marquis varieties in the order named. The Minnesota lines, excluding the durum wheats which proved to be least adapted to Aroostok conditions and should be treated separately by themselves, show an average crude protein content practically equal to that of Canada Red. The average protein content of all Aroostook lines taken together is 13.81 per cent while the Minnesota lines with an average of 14.36 show a hardly significant difference of about 0.5 per cent.

It will be of interest to compare the protein content of the Minnesota lines originally grown in Minnesota with that of their progeny grown one season in Aroostook. In Table 6 are tabulated the data on the protein content of the original Minnesota grown seed and of the Aroostook grown progeny.

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*Credit is due to the Chemistry Department of this Station for the chemical analyses of wheat of the pure lines in 1917 and 1918.

TABLE 5.

Crude Protein Content of Pure Lines of Wheat Grown at Aroostook Farm in 1917.

AROOSTOOK LINES

Line No.	Selected from Variety	Plot No.	Nitrogen	Crude Protein (N x 5.7) Per cent
2390	Red Fife	564	2.62	14.93
2429	Red Fife	557	2.50	14.25
2379	Red Fife	553	2.46	14.02
2461	Red Fife	566	2.45	13.97
2389	Red Fife	555	2.44	13.91
2393	Red Fife	558	2.44	13.91
2422	Red Fife	551	2.42	13.79
2386	Red Fife	556	2.40	13.68
2395	Red Fife	559	2.39	13.62
2434	Red Fife	560	2.34	13.34
2436	Red Fife	561	2.34	13.34
2423	Red Fife	552	2.33	13.20
2444	Red Fife	563	2.30	13.11
2385	Red Fife	565	2.28	13.00
2439	Red Fife	562	2.24	12.77
Average			2.40	13.68
2384	Bluestem	592	2.63	14.99
2635	Bluestem	646	2.59	14.76
2387	Bluestem	594	2.52	14.36
2394	Bluestem	642	2.51	14.31
2382	Bluestem	597	2.50	14.25
2404	Bluestem	645	2.48	14.14
2510	Bluestem	591	2.47	14.08
2506	Bluestem	589	2.44	13.91
2507	Bluestem	590	2.43	13.85
2514	Bluestem	593	2.41	13.74
2412	Bluestem	596	2.40	13.68
2391	Bluestem	644	2.39	13.62
2521	Bluestem	599	2.39	13.62
2520	Bluestem	598	2.38	13.57
2516	Bluestem	595	2.37	13.51
2503	Bluestem	587	2.34	13.34
2505	Bluestem	588	2.31	13.17
2502	Bluestem	586	2.30	13.11
2501	Bluestem	585	2.28	13.00
2500	Bluestem	584	2.07	11.81
Average			2.41	13.74
2408	Preston	579	2.66	15.16
2402	Preston	575	2.63	14.99
2381	Preston	637	2.54	14.48
2397	Preston	638	2.52	14.36
2411	Preston	581	2.52	14.36
2388	Preston	571	2.52	14.36
2400	Preston	576	2.48	14.14
2383	Preston	578	2.46	14.02
2414	Preston	569	2.44	13.91
2477	Preston	572	2.42	13.79
2495	Preston	583	2.38	13.57
2409	Preston	577	2.36	13.45
2405	Preston	574	2.36	13.45
2470	Preston	568	2.36	13.45
2494	Preston	580	2.35	13.40
2498	Preston	582	2.33	13.21
2380	Preston	570	2.26	12.88

Crude Protein Content of Pure Lines of Wheat Grown at Aroostook Farm in 1917.—Concluded.

Line No.	Selected from Variety	Plot No.	Nitrogen	Crude Protein (N x 5.7) Per cent
Average			2.45	13.94
2410	Marquis	620	2.58	14.71
2556	Marquis	622	2.45	13.97
2555	Marquis	621	2.41	13.74
2587	Marquis	630	2.36	13.45
2583	Marquis	629	2.34	13.34
2401	Marquis	632	2.30	13.11
2398	Marquis	624	2.29	13.05
2558	Marquis	623	2.29	13.05
2561	Marquis	625	2.26	12.88
2588	Marquis	631	2.26	12.88
2579	Marquis	628	2.24	12.77
2569	Marquis	627	2.20	12.54
Average			2.33	13.29
2374	Canada Red	612	2.76	15.73
2377	Canada Red	613	2.64	15.05
2378	Canada Red	609	2.62	14.93
2373	Canada Red	604	2.61	14.88
2376	Canada Red	608	2.61	14.88
2372	Canada Red	605	2.61	14.88
2375	Canada Red	614	2.58	14.71
2544	Canada Red	618	2.56	14.59
2371	Canada Red	619	2.54	14.48
2543	Canada Red	617	2.50	14.25
2535	Canada Red	610	2.50	14.25
2531	Canada Red	607	2.46	14.02
2529	Canada Red	606	2.44	13.91
2523	Canada Red	601	2.42	13.79
2524	Canada Red	602	2.40	13.68
2522	Canada Red	600	2.38	13.57
2525	Canada Red	603	2.26	12.88
2536	Canada Red	611	2.24	12.77
Average			2.51	14.30
2370	Unnamed	616	2.59	14.76
2415	Unnamed	640	2.52	14.36
2607	Unnamed	641	2.50	14.25
2479	Unnamed	633	2.48	14.14
2406	Unnamed	639	2.38	13.57
2597	Unnamed	636	2.33	13.28
2592	Unnamed	635	2.32	13.22
2465	Unnamed	634	2.28	13.00
2396	Unnamed	567	2.27	12.94
Average			2.40	13.69

MINNESOTA LINES.

Maine Access. No.	Minnesota Accession No.	N. S. N.	Selected from Variety	Plot No.	Nitrogen	Crude Protein (N x 5.7)
183	1011	I-15-161	Velvet Chaff	654	2.71	15.45
189	169	I-16-19	Haynes Bluestem	648	2.52	14.36
186	1037	I-12-1	Royalton (Red)	651	2.48	14.14
185	1037	I-12-6	Royalton (White)	647	2.48	14.14
181	188x188	II-06-39	Preston x Preston	652	2.47	14.08
187	1239	I-16-81	Marquis	650	2.46	14.02
182	337	I-00-45	Speltz Marz (durum)	653	2.18	12.43
184	470	I-00-52	Hedge Row (durum)	649	2.04	11.59
Average					2.42	13.79
Average for Minnesota Lines (exclusive of durum lines)					2.52	14.36
Average for Aroostook Lines					2.43	13.81

A comparison of the two sets of data given in Table 6 shows that the Minnesota lines when transferred into Aroostook and grown there one season suffered a loss of only about 0.8 per cent of protein. If we further add that the original Minnesota grown seed, when analyzed for protein was considerably older, and having a lower moisture content than the Aroostook progeny grown from it, the latter's loss of 0.8 per cent of protein as compared with the former becomes negligible.

TABLE 6.

Comparison of the Protein Content of the Minnesota Grown Lines with that of their Aroostook Grown Progeny.

Maine Access. No.	Minnesota Accession No.	N. S. N.	Selected from Variety	Original Minnesota grown seed		Aroostook grown progeny	
				Nitrogen in per cent	Protein (Nx5.7) in per cent	Nitrogen in per cent	Protein (Nx5.7) in per cent
182	337	I-00-45	Speltz Marz (durum)	2.75	15.68	2.18	12.43
186	1037	I-12-1	Royalton (Red)	2.72	15.50	2.48	14.14
183	1011	I-15-161	Velvet Chaff	2.71	15.45	2.71	15.45
184	470	I-00-52	Hedge Row (durum)	2.68	15.28	2.04	11.59
185	1037	I-12-6	Royalton (White)	2.55	14.54	2.48	14.14
Average				2.68	15.30	2.42	13.79
Average (excluding durum lines)				2.66	15.17	2.52	14.36

A consideration of the changes caused by the Aroostook environment in the weight, size, shape of kernel as well as in the protein content of the original Minnesota grown seed very clearly indicates that the effect of the Aroostook environment upon the Minnesota grown wheats is decidedly more noticeable in the physical characteristics than in the crude protein content. A very notable exception are the two durum lines. The Minnesota grown Speltz Marz heads the list of the Minnesota lines in regard to protein content; at the end of one season's growth in Aroostook this line shows the second lowest protein content of all 99 lines analyzed. The second durum line, Hedge Row, suffered an even greater loss in nitrogen —3.69 per cent. By contrast, the Aroostook grown Velvet Chaff line shows a protein content identical with that of the Minnesota grown seed, while

Royalton (White) and Royalton (Red) suffered only a loss of 0.40 and 1.36 per cent, respectively. The grain of the durum lines showed also the most marked deterioration in the physical characteristics. This tendency of the durum wheats to rapidly deteriorate under Aroostook conditions was also borne out by the results from the 1918 crop which will be considered below.

A comparison of the average protein content of the Aroostook wheat lines with the average protein content of the chief classes of American wheats as given by L. M. Thomas[20] is of interest. In his extensive investigations made in the Office of Grain Standardization and involving several hundreds of samples, Thomas found the average crude protein content of the soft red winter, durum, hard red winter, and hard red spring wheats to be: 10.6, 14.3, 12.1, 12.9 per cent, respectively. The average crude protein content of the Aroostook pure lines of wheat grown in 1917 was found to be 13.81 per cent or nearly 1 per cent higher than the average for the class of hard red spring wheats as given by Thomas.

CHEMICAL ANALYSIS OF THE PURE LINES GROWN IN 1918.

At the stage of propagation of the pure lines reached with the harvest of the 1918 crop there was enough seed to make a complete chemical analysis and baking tests of these wheats. Of the 99 lines grown in 1917 only 44 were continued in 1918 and of these 40 were subjected to a chemical analysis. This reduction was due to the elimination of strains lacking in protein or in strength of straw and other desirable physical characteristics. The results of the chemical analysis of the 40 lines are presented in Table 7. The lines within each variety are grouped according to their protein content.

A study of the data in Table 7 will reveal first a general lowering of the average protein content of the pure lines as compared with the protein content of the 1917 crop. The variation in the average protein content ranges from 11.76 to 13.30 per cent as against 13.29 to 14.36 per cent for the 1917 crop when

[20]Thomas, L. M. A Comparison of Several Classes of American Wheats and a Consideration of Some Factors Influencing Quality. U. S. Dept. Agr. Bu. of Plant Ind. and Bu. of Markets 1917, Bul. 557, pp. 1-28.

the range of variation was somewhat narrower than in 1918. The growing conditions of the 1918 season had admittedly a levelling down effect upon the protein content of the pure lines. Apart from the seasonal influences there were other factors in

TABLE 7.

Chemical Composition of Pure Lines of Wheat Grown at Aroostook Farm in 1918.

AROOSTOOK LINES.

Line No.	Selected from Variety	Plot No.	Moisture	Ash	Nitrogen	Protein (Nx5.7)	Fat	Crude Fiber
2385	Red Fife	870	7.13	1.92	2.55	14.54	2.64	2.18
2390	Red Fife	876	7.98	2.05	2.42	13.79	2.42	2.49
2389	Red Fife	875	8.63	2.04	2.25	12.83	2.54	2.04
2393	Red Fife	880	9.88	1.98	2.14	12.20	2.01	2.10
2379	Red Fife	864	8.51	2.03	2.14	12.20	2.57	2.19
2386	Red Fife	871	9.65	1.95	2.13	12.14	2.24	2.19
2395	Red Fife	882	9.17	1.92	2.06	11.14	2.61	2.09
Average			8.71	1.98	2.24	12.77	2.47	2.18
2404	Bluestem	890	7.28	2.07	2.36	13.45	2.67	2.25
2391	Bluestem	877	7.52	2.01	2.34	13.34	2.38	2.26
2394	Bluestem	881	7.17	2.07	2.22	12.65	2.57	2.27
2387	Bluestem	873	8.74	2.16	2.19	12.48	2.56	2.20
2384	Bluestem	869	9.95	2.01	2.09	11.91	2.30	2.18
Average			8.08	2.06	2.24	12.77	2.50	2.23
2381	Preston	866	7.88	2.15	2.54	14.48	2.95	2.19
2402	Preston	893	8.71	2.12	2.42	13.79	2.54	2.36
2411	Preston	902	7.33	2.24	2.42	13.79	2.59	2.23
2397	Preston	884	8.58	2.11	2.34	13.34	2.53	2.16
2383	Preston	868	8.03	2.29	2.32	13.22	2.21	2.44
2414	Prseton	910	8.70	2.06	2.29	13.05	2.31	2.15
2388	Preston	874	9.17	1.96	2.26	12.88	2.36	2.23
2409	Preston	900	9.83	1.99	2.09	11.91	2.42	2.09
2405	Preston	891	9.21	2.08	2.02	11.51	2.88	2.33
2400	Preston	907	9.24	2.01	1.93	11.00	2.38	2.19
Average			8.67	2.10	2.26	12.91	2.52	2.24
2398	Marquis	885	7.83	2.16	2.12	12.08	2.46	2.53
2401	Marquis	887	9.05	1.87	2.09	11.91	2.38	1.99
2410	Marquis	895	7.77	1.99	1.98	11.29	2.75	2.28
Average			8.22	2.01	2.06	11.76	2.53	2.27
2374	Canada Red	901	8.05	2.35	2.40	13.68	2.70	2.41
2377	Canada Red	908	8.44	2.16	2.37	13.51	2.20	2.54
2373	Canada Red	899	8.46	2.14	2.35	13.40	2.63	2.53
2376	Canada Red	905	7.61	2.04	2.33	13.28	2.28	2.68
2375	Canada Red	904	7.93	2.09	2.12	12.08	2.50	2.49
2396	Canada Red	883	9.85	2.12	2.08	11.86	2.50	2.34
Average			8.98	2.16	2.32	13.20	2.46	2.53
2370	Unnamed	862	8.28	1.95	2.28	12.99	2.25	2.24
2415	Unnamed	911	8.29	1.91	2.16	12.31	2.49	2.23
2406	Unnamed	892	8.89	1.90	2.03	11.57	2.32	2.39
Average			8.49	1.92	2.16	12.29	2.35	2.29

Chemical Composition of Pure Lines of Wheat Grown at Aroostook Farm in 1918.—Concluded.

MINNESOTA LINES.

Accession No.	Selected from Variety	Moisture	Ash	Nitrogen	Protein (Nx5.7)	Fat	Crude Fiber
187	Marquis	8.04	2.01	2.44	13.91	2.85	2.23
186	Royalton (Red)	7.07	2.08	2.38	13.57	2.74	2.21
185	Royalton (White)	9.44	2.02	2.32	13.22	2.31	2.23
180	Haynes Bluestem	7.13	2.05	2.27	12.94	2.74	2.22
183	Velvet Chaff	9.20	1.97	2.26	12.88	2.46	2.14
182	Speltz Marz (durum)	8.80	1.93	1.83	10.43	2.50	2.08
Average for Minnesota lines		8.28	2.03	2.25	12.83	2.60	2.19
Average for Minnesota lines exeept durum		8.18	2.03	2.33	12.30	2.62	2.21

regard to which the crops of 1917 and 1918 differed. In 1917 the wheat lines did not grow on typical Caribou loam but on a darker soil with more abundant moisture and possibly more humus, which may have accounted for the higher protein content in 1917. Further, in 1917 the wheat lines all grew in one two-thousandth acre plots while in 1918 the area ranged from one two-hundredth to one-fortieth acre. The smaller tract occupied by the wheats in 1917 presented probably a greater uniformity of soil conditions than the larger area in 1918 which possibly accounted for a narrower range of variation in the protein content.

It will now be of interest to study the relationship between the protein content in 1917 and 1918. Considering first the varieties as a whole we note on consulting Tables 5 and 7 that notwithstanding the comparatively small differences in their protein content the varieties rank practically in the same order with respect to protein content in 1918 as they did in 1917. This is brought out more clearly by bringing together the average protein contents of the pure lines of each variety for each year as shown in Table 8. While the difference between the averages are small the data given in Table 8 indicate a tendency for the varieties as a whole to preserve their respective rank with respect to protein content.

As the average of these varieties are determined by the values of their component strains it will be instructive to examine the behavior of the individual lines with respect to their protein content from year to year. It will be remembered that 99 lines

TABLE 8.

Relation Between the Average Protein Content for the Pure Lines of Each Variety in 1917 and 1918.

Parent Variety of Pure Lines	Average Protein Content in per cent	
	1917	1918
Minnesota Lines	14.36	13.30
Canada Red	14.30	13.20
Preston	13.94	12.91
Bluestem	13.74	12.77
Unnamed	13.69	12.29
Red Fife	13.68	12.77
Marquis	13.29	11.76

were analyzed in 1917. In 1918 only 44 lines were continued and of these 40 were analyzed so that only for these 40 lines could the variation in the protein content in 1917 and 1918 be determined. The protein content of each line in 1917 was correlated with the protein content of the same line in 1918 with a resulting correlation coefficient of $0.381 \pm .092$. This coefficient as judged by its probable error is significant despite the small number of individuals, and indicates that with a number of pure lines here considered the protein content was transmitted from one year to the next. This is in accord with the observations reported by Freeman[21] who found for the character hardness or flintiness of wheat which is regarded as closely associated with high nitrogen, that the "differences (in percentage of hard grains) were varietal and tended to persist in the same strains from year to year." Freeman's pure lines were selected from a commercial variety of Turkey wheat and the percentage of hard grains in 1914 correlated with percentage of hard grains in 1915=57% $\pm$4%; the percentage of hard grains in 1915 with percentage of hard grains in 1916=33%$\pm$5% (L. c. p. 27).

The degree of correlation between the protein contents of wheat varieties from one year to the next will depend upon the number of strains which under a given set of environmental condititions will tend to retain their relative rank with respect to

[21]Freeman, Geo. F. A Mechanical Explanation of Progressive Changes in the Proportions of Hard and Soft Kernels in Wheat. Jour. Am. Soc. Agr. 1918, v. 10, pp. 23-28.

protein content. Since the coefficient of correlation referred to above was obtained by grouping pure strains originally selected from different varieties it became a matter of interest to determine to what extent each of the respective parent varieties influenced the value of that coefficient. A tabulation of the different strains within each variety with respect to their relative rank in protein content in 1917 and 1918 brought out the fact that the varieties Canada Red, Preston, Red Fife and Unnamed furnished most of the strains which retained their relative rank in protein content from one year to the next, while with the Minnesota lines and the Marquis and Bluestem varieties the behavior of the lines with respect to this character was more erratic. It may be of interest to note in this connection that the varieties Preston, Canada Red and Red Fife which contained a large number of lines retaining their relative rank in protein content from year to year have been grown for years in Aroostook and Eastern Canada whereas the other varieties whose lines did not show a consistent behavior with respect to protein content have only very recently been introduced into Aroostook. This fact may serve to explain the different behavior of these two groups of strains with respect to their protein rank from one year to the next. A commercial variety is a mixed population composed of a number of different strains. These strains may possess a varied degree of response to the factors of environment of a given locality. If a commercial variety is grown for a number of years in one locality its component strains may be expected to have an established degree of reaction to the environment of that locality. Strains selected out of such a variety will tend to retain their relative rank in respect to a given quantitative character. On the other hand, varieties introduced into a new environment can not be expected in the first years of adaptation to segregate out strains with a fixed type of response to the new environment in regard to their quantitative characters. This brief consideration may acount for the different behavior of the local, Aroostook grown and the Minnesota strains.

BAKING TESTS OF THE PURE LINES.

The wheat of thirty-one pure lines of the 1918 crop was ground in a small experimental mill in the laboratory of the Russell-Miller Milling Co., Minneapolis, and the flour subjected to

a chemical analysis and a baking test in the laboratory of the Ward Baking Company, New York. The writer is greatly indebted to Dr. Chas. Hoffman, Chief Chemist of the Ward Baking Company for his careful study of these flours for strength and baking quality.

The results of the chemical analysis of these flours are given in Table 9. The lines are grouped according to their parent varieties and their dry gluten rank.

From Table 9 the considerable variations in the gluten content will be first noted. With a number of strains the percentage of dry gluten is rather high, several of the Aroostook lines exceeding the Minnesota lines in gluten content. Except for a few striking exceptions, there appears to be a relation between the amount and quality of gluten. The Red Fife and Bluestem varieties furnished a large number of strains with good quality glutens while the Preston, Unnamed and Marquis show a large percentage of strains with fair to poor quality of gluten. The Marquis lines showed uniformly short, stiff glutens of only fair quality. The Minnesota lines with the exception of durum and Marquis furnished strong glutens of good quality.

The data from the baking test with regard to water used, volume of loaf, texture, color of crumb and external appearance of loaf are presented in Table 10. According to Dr. Hoffman's report the following ingredients were used in each case:

Flour	300 grams
Water	Amount to give correct stiffness
Sugar	20 grams
Salt	4½ grams
Yeast	5 grams
Arkady Yeast Food	1½ grams

Temperature set 82° F.

Time of fermentation 4¼ hours. This is the time when the dough is mixed until it is moulded ready for the pan.

All doughs were well moulded by machinery, but mixed by hand. Baking was done under factory conditions.

TABLE 9.

Results of Chemical Analysis of Flours From Pure Lines of Wheat Grown at Aroostook Farm. 1918 Crop.

AROOSTOOK LINES.

Line No.	Selected from Variety	Ash per cent	Moisture per cent	Gluten		Ratio Wet to Dry Gluten	Condition of Gluten
				Wet per cent	Dry per cent		
2390	Red Fife	0.70	8.40	37.96	13.13	2.89	Soft and sticky—weak gluten
2385	Red Fife	0.60	8.50	36.50	12.74	2.87	Soft elastic gluten with good expanding quality
2389	Red Fife	0.70	8.30	33.55	12.18	2.75	Tough gluten of fair quality
2386	Red Fife	0.67	8.38	32.78	11.78	2.78	Tough, strong gluten
2379	Red Fife	0.66	8.50	33.60	11.78	2.85	Gluten strong and elastic
2393	Red Fife	0.68	8.30	33.70	11.67	2.88	Good quality gluten, strong and elastic
2395	Red Fife	0.70	8.50	32.25	11.26	2.89	Medium quality gluten —somewhat dead
Average		0.67	8.41	34.33	12.08	2.83	
2391	Bluestem	0.77	8.40	35.40	12.35	2.87	Tough, elastic gluten
2387	Bluestem	0.74	8.32	34.55	12.25	2.82	Very good, strong gluten
2394	Bluestem	0.78	8.47	33.85	11.95	2.83	Strong, tough gluten
2384	Bluestem	0.67	8.57	32.05	11.28	2.84	Medium softness with fair quality
Average		0.74	8.44	33.88	11.98	2.84	
2402	Preston	0.72	8.53	40.38	13.26	3.04	Soft and sticky, strength poor
2397	Preston	0.66	8.60	39.93	12.84	3.19	Soft and elastic—good quality
2383	Preston	0.86	8.70	37.47	12.83	2.92	Gluten soft and sticky, fair quality
2414	Preston	0.68	8.14	35.05	12.30	2.85	Elastic gluten of very good quality
2388	Preston	0.64	8.20	35.45	12.13	2.92	Strong gluten with very good expanding quality
2409	Preston	0.79	8.53	34.25	11.85	2.89	Very soft and sticky
2405	Preston	0.79	8.38	32.85	11.23	2.93	Soft dead gluten—no elasticity
2400	Preston	0.74	8.78	31.50	10.89	2.80	Soft sticky, of poor quality
Average		0.74	8.48	35.86	12.17	2.94	
2398	Marquis	0.81	8.80	31.83	11.69	2.72	Stiff, tough gluten—shows fair quality
2410	Marquis	0.77	8.49	29.20	10.60	2.75	Short, stiff gluten, fair strength
Average		0.79	8.65	30.52	11.15	2.74	
2373	Canada Red	0.70	8.50	39.21	13.23	2.96	Soft but elastic and of good quality
2396	Canada Red	0.69	8.20	31.48	10.80	2.91	Soft and sticky, very low quality
Average		0.69	8.35	35.35	12.02	2.94	

Results of Chemical Analysis of Flours From Pure Lines of Wheat Grown at Aroostook Farm. 1918 Crop.
—Concluded.

Line No.	Selected from Variety	Ash per cent	Moisture per cent	Gluten		Ratio Wet to Dry Gluten	Condition of Gluten
				Wet per cent	Dry per cent		
2415	Unnamed	0.62	8.40	37.40	12.22	3.06	Soft and sticky, lacks strength
2370	Unnamed	0.70	8.42	32.65	11.53	2.83	Soft, dead gluten—no life
2406	Unnamed	0.66	8.56	29.53	10.31	2.86	Soft, putty-like gluten
Average		0.66	8.46	33.19	11.35	2.92	

MINNESOTA LINES.

Accession No.	Selected from Variety	Ash per cent	Moisture per cent	Gluten		Ratio Wet to Dry Gluten	Condition of Gluten
				Wet per cent	Dry per cent		
186	Royalton (Red)	0.74	8.20	36.28	12.69	2.86	Very good gluten with strong expansive qualities
185	Royalton (White)	0.68	8.28	34.28	12.28	2.81	Strong, elastic gluten
189	Haynes Bluestem	0.72	8.30	34.40	11.83	2.91	Tough and strong
187	Marquis	0.77	8.30	32.25	11.56	2.79	Short and stiff of medium quality
182	Speltz Marz (durum)	0.90	8.49	27.00	9.93	2.72	Very dead-like and non-elastic
Average		0.76	8.31	32.84	11.66	2.82	
Average (excluding durum)		0.73	8.25	34.30	12.09	2.86	

In Table 10 the pure lines are grouped within their parent varieties according to the volume, expressed in cubic centimeters, of bread loaf produced from their flour. A photograph of each loaf baked from the flour of each strain is given in the accompanying figures. From these photographs the size, volume, texture and general appearance of each loaf will be noted. A study of the data given in Table 10 will show a number of strains producing a bread of good volume and very good appearance. As in the case of other characters the variation in the size of bread loaf is very marked. The Red Fife line No. 2393 produced a

bread loaf with the highest volume—2221cc.—of very good texture and good color. Very similar qualities were shown by the Bluestem line 2391 with a loaf volume of 2209 c.c. The third highest loaf volume was produced from flour of another Red Fife strain—No. 2385. The best Minnesota line, Royalton (Red) ranks fourth in volume of loaf. On comparing the data from

TABLE 10.

Baking Tests of Flours from Pure Lines of Wheat Grown at Aroostook Farm. 1918 Crop.

AROOSTOOK LINES

Line No.	Selected from Variety	Grams of water used	Loaf Volume in cubic centimeters*	Texture	Color of Crumb	External Appearance
2393	Red Fife	210	2,221	Very good	Good	Excellent baking quality—produced nice appearing loaf
2385	Red Fife	213	2,153	Close	White with velvety sheen	Very good size and appearance. Excellent baking qualities
2390	Red Fife	210	2,028	Good, close	Good	Flour produces good sized loaf, but lacks baking strength
2389	Red Fife	210	2,028	Very good	Good	Volume good. Has strength and makes good appearing loaf
2386	Red Fife	210	2,017	Fair	Fair	Tendency of dough to tear during proofing, causing a rough appearance of loaf
2379	Red Fife	205	1,903	Very good	White	Size of loaf fair but flour shows good baking quality
2395	Red Fife	210	1,881	Coarse	Fair	Poor baking qualities, appearance of loaf fair
2391	Bluestem	210	2,209	Very good	Good	Very good appearing loaf. Flour has good baking strength
2394	Bluestem	210	2,096	Fair	Fair	Volume good. Flour has good baking qualities
2387	Bluestem	210	1,983	Poor	Fair	Volume good. Flour shows strength and qualities
2384	Bluestem	205	1,813	Fair	Good	Fair size to loaf, fair baking quality
2388	Preston	210	2,068	Close	Very good—white	Volume good. Appearance good. Baking quality very good
2397	Preston	205	2,028	Very close	Good	Volume good. Shows good baking qualities
2414	Preston	210	1,983	Very good	Very good	Good volume and appearance, good quality for baking
2402	Preston	205	1,892	Good	Good	Good appearing loaf. Gluten lacks strength for good baking results

Baking Tests of Flours from Pure Lines of Wheat Grown at Aroostook Farm. 1918 Crop.—Concluded.

Line No.	Selected from Variety	Grams of water used	Loaf Volume in cubic centimeters*	Texture	Color of Crumb	External Appearance
2400	Preston	200	1,869	Fair	Fair	Has poor baking qualities. Lacks strength to give proper expansion
2383	Preston	205	1,858	Fair	Dark	Appearanee good. Has good baking qualities
2409	Preston	200	1,858	Good	Fair	Poor quality for bread baking
2405	Preston	200	1,773	Close	Dark	Fair appearing loaf, but gluten too dead to give proper expansion
2398	Marquis	210	1,949	Good	Dark gray	Volume good. Flour has strength for baking
2410	Marquis	210	1,858	Coarse	Fair	Fair baking quality
2373	Canada Red	205	2,017	Good	Good	Volume good but strength too low for good baking results
2396	Canada Red	205	1,745	Coarse	Dark	Volume poor. Appearance of loaf fair. Poor baking qualities
2415	Unnamed	200	1,926	Close	Fair	Appearance of loaf fair, but gluten too weak to prevent tearing on the side of loaf
2370	Unnamed	200	1,756	Coarse	Dark	Appearance of loaf good but lacks volume. Quality lacking
2406	Unnamed	190	1,518	Very coarse	Dark	Very poor quality flour for bread baking

MINNESOTA LINES

Accession No.	Selected from Variety	Grams of water used	Loaf Volume in cubic centimeters*	Texture	Color of Crumb	External Appearance
186	Royalton (Red)	210	2,079	Good	Slightly gray	Very good volume and appearance. Very good quality
185	Royalton (White)	210	2,028	Good, close	Good	Volume and expansion showed good quality
187	Marquis	210	1,903	Very coarse	Dark	Fair appearance of loaf, but flour lacks strength
180	Haynes Bluestem	210	1,881	Close	Slightly gray	Size of loaf good, appearance good. Baking qualities very good
182	Speltz Marz (durum)	190	1,360	Very coarse	Dark	No strength to give size and appearance to loaf

*Calculated to 340 grams of flour per each loaf.

the baking test with the results of the chemical analysis of the flours it will be noted that the quality of gluten is very well reflected in the volume and appearance of the bread loaves. With a few rather striking exceptions the volume of loaf appears to follow in a number of cases also the quantity of gluten. This point will be recurred to later.

Since the volume of loaf is at present the most reliable index of flour strength, and further, one of the most important factors in determining the commercial value of bread wheat, it will be of interest to determine how the wheats from the pure lines here considered would rank among the chief American wheats. We may here again refer to the study of several classes of American wheats by L. M. Thomas.[22] On the basis of extensive baking tests involving 1386 samples Thomas found the following average volume for each of the five classes of American wheats:

Soft white	1,907 c.c.
Soft red winter	1,965 c.c.
Durum wheat	2,070 c.c.
Hard red winter	2,219 c.c.
Hard red spring	2,421 c.c.

Comparing our best line 2393 having a volume of 2,221 c.c. we find that it falls just 200 c.c. short of the average volume of its own class of wheat, the hard spring wheat. From a diagram in Thomas' bulletin in which the distribution of the 574 samples with regard to volume in the hard spring wheat class are illustrated we may note that about 15 per cent of hard spring wheat samples had a loaf volume lower than some of our best lines. Further reference to the average loaf volume of American wheats given above, shows that our best lines furnished a loaf volume very considerably higher than the average of the two classes of soft wheat, a higher than the average of the durum class, and equal to the average of the hard red winter class. From this comparison we note that our best lines of wheat are as strong as 15 per cent of the hard red spring wheats and 50 per cent of the hard red winter wheats.

The data given by Thomas are based on samples taken from the crops of 1908 to 1913 inclusive. If we should consider the

[22]L.c. pp. 18-19.

strength of wheats determined for one year in a state growing some of the best spring wheats, for instance, North Dakota, we would find that the size of loaf of our best lines approaches still closer the size of the strong wheats grown there. Thus in a report on the baking data for the 1915 crop of North Dakota[23] wheat we find that the average loaf volume of Bluestem, Fife, Velvet Chaff and Marquis, including all grades is 2307 c.c. Including only the two best paid classes of these four wheats, No. 1 Hard, and No. 1, the average volume of loaf from the flour of these two grades of wheat is only 2271 c.c. or only 50 c.c. above the volume of the best of our pure strains. While these comparisons are not quite fair they nevertheless convey some idea as to the possibilities of growing strong wheats in Northern Maine.

Relative to other points determining the quality of bread, reference to Table 10 will show that the texture and color of crumb with a relatively large proportion of the pure strains was found to be good or very good. Especially the strains of the Red Fife and Preston varieties excel on this point. Most of these breads possessed excellent eating qualities.

RELATION BETWEEN PROTEIN, GLUTEN CONTENT AND SIZE OF BREAD LOAF.

With the data on crude protein, dry gluten and loaf volume for these pure lines at hand it is very desirable from the breeding point of view to examine if there is any relation between these three characters which would be of diagnostic value in the breeding work. In Table 11 the pure lines are grouped within their respective parent varieties in the order of their crude protein content with the corresponding rank in gluten and loaf volume.

An inspection of Table 11 will reveal an undeniable relationship between the crude protein content, dry gluten and the size of loaf. While this relation is not quite regularly consistent it is nevertheless distinct. In regard to the degree of relationship between these three factors the data given in Table 11

[23]Sanderson, Thomas. The Milling and Baking Data for the 1915 Crop of Wheat. 1917, N. Dakota Bull. No. 132, pp. 61-94.

TABLE 11

Relative Rank of the Pure Lines with Respect to Crude Protein, Dry Gluten and Loaf Volume. 1918 Crop.

AROOSTOOK LINES.

Line No.	Variety	Crude Protein		Dry Gluten		Loaf Volume	
		per cent	Rank	per cent	Rank	c.c.	Rank
2385	Red Fife	14.54	1	12.74	2	2,153	2
2390	Red Fife	13.79	2	13.13	1	2,028	3
2389	Red Fife	12.83	3	12.18	3	2,028	4
2393	Red Fife	12.20	4	11.67	4	2,221	1
2379	Red Fife	12.20	5	11.78	5	1,903	6
2386	Red Fife	12.14	6	11.78	6	2,017	5
2395	Red Fife	11.74	7	11.26	7	1,881	7
2391	Bluestem	13.34	1	12.35	1	2,209	1
2394	Bluestem	12.65	2	11.95	3	2,096	2
2387	Bluestem	12.48	3	12.25	2	1,983	3
2384	Bluestem	11.91	4	11.28	4	1,813	4
2402	Preston	13.79	1	13.26	1	1,892	4
2397	Preston	13.34	2	12.84	2	2,028	2
2383	Preston	13.22	3	12.83	3	1,858	6
2414	Preston	13.05	4	12.39	4	1,983	3
2388	Preston	12.88	5	12.13	5	2 068	1
2409	Preston	11.91	6	11.85	6	1,858	7
2405	Preston	11.51	7	11.23	7	1,773	8
2400	Prestou	11.00	8	10.89	8	1,869	5
2398	Marquis	12.08	1	11.69	1	1,949	1
2410	Marquis	11.29	2	10.60	2	1,858	2
2373	Canada Red	13.40	1	13.23	1	2,017	1
2396	Canada Red	11.86	2	10.80	2	1,745	2
2370	Unnamed	12.99	1	11.53	2	1 756	2
2415	Unnamed	12.31	2	12.22	1	1,926	1
2406	Unnamed	11.57	3	10.31	3	1.518	3

MINNESOTA LINES.

Accession No.	Variety	Crude Protein		Dry Gluten		Loaf Volume	
		per cent	Rank	per cent	Rank	c.c.	Rank
187	Marquis	13.91	1	11.56	4	1,903	3
186	Royalton (Red)	13.57	2	12.69	1	2,079	1
185	Royalton (White)	13.22	3	12.28	2	2,028	2
180	Haynes Bluestem	12.94	4	11.83	3	1,881	4
182	Speltz Marz (durum)	10.43	5	9.93	5	1,360	5

indicate a close relation between the protein and dry gluten. Indeed, the ranks of the crude protein and the dry gluten are completely indentical for the strains of the Preston, Marquis,

Canada Red, and nearly identical for the strains of Red Fife and Bluestem. In regard to the relation of the two chemical components, protein and gluten, to the baking strength there appears to be, on the whole, some relation between the gluten content and size as well as a still less consistent relation between protein and loaf volume.

These relations are of importance especially as they have been established in this case for pure strains of wheat grown at one limited centre, when the evidence for or against these relations has hitherto been based almost exclusively on analysis of samples from commercial varieties. In this connection it is of special interest to cite the results of two chemists, who worked with materials of an entirely different nature. Shutt[24] analyzing flours from wheats representing for the most part pure strains selected and bred pure by Dr. Chas. E. Saunders arrived at the conclusion that "between the protein, gliadin and wet and dry gluten there is a distinct relationship, but there is no evidence of a definite or absolute ratio. The results from both series of flours clearly indicate a distinct relationship between these chemical data (protein, gliadin and gluten) and 'baking strength' —a figure made up chiefly of the values for volume, shape and weight of loaf." Olson,[25] on the other hand, working with samples of flours from unidentified varieties and received from mills located in 12 different States concluded that there is no relation between the quality of the flour and the total nitrogen and gluten content. "The volumes of loaves appeared to be inversely proportional to the gluten content."

DISCUSSION AND CONCLUSIONS.

An analysis of the data here presented brings out the fact that pure strains of wheat isolated from commercial varieties when grown under the same environmental conditions show very distinct differences with respect to the physical and chemical characteristics and the bread making value of their grain. The very small tract of land upon which these pure lines grew,

[24]Shutt, T. F. The Relationship of Composition to Bread-making value. 1907. Centr. Exp. Farm, Can. Bull. 57, pp. 27-51.

[25]Olson, G. A. Wheat and Flour Investigations—V, 1917, Wash. Agr. Exp. Sta. Bull. No. 144, pp. 1-86.

and for which a very considerable degree of homogeneity may safely be assumed, lends particular significance to these differences. For one of these characters, viz, the crude protein content, whose behavior alone could be studied from one year to the next, it was shown that these differences are not mere fluctuations but the result of inherent tendencies as evidenced by the coefficient of correlation between the values of one year and those of the next. Of the physical characteristics the kernel weight, the hardness as measured by the percentage of yellow berries, and the color show marked differences. Even in the nursery rows where the strains grew side by side the degree of hardness of the different lines was so marked that out of the original 259 strains 158 were discarded as being soft and opaque. This character while very susceptible to the environment is regarded by Freeman (Loc. cit. 1918) as being controlled by genetic factors which determine the greater or less sensitivity of this character to the environment. Leith,[26] who also studied the inheritance of the yellow berry, found that while there is no difference between the yellow and hard berry of the same pure line in the production of yellow berry in their progeny, there is a very considerable difference between pure lines in their tendency to reproduce hard berries.

No less pronounced are the differences between the individual lines with respect to the chemical characteristics as will be seen from Tables 5 and 7. The average protein content for all strains in 1917 was higher than in 1918. But in spite of the seasonal variation of the environment affecting the absolute quantity of the protein the fact remains that the individual strains tended to retain their relative protein rank regardless of the seasonal average for this character.

From the close association between protein and gluten it may be inferred that there is a tendency for the pure strains to retain also their gluten rank, though there has been no opportunity yet to study the behavior of this character from year to year.

Perhaps the most pronounced differences between the pure lines are reflected in the quality of their glutens and in the size of bread loaf baked from their flours, as shown in Tables 9 and 10. While the present data do not convey any informa-

[26]B. D. Leith, Loc. cit.

tion as to whether these two characters are heritable, the results secured by Biffen[27], Howard, Leake and Howard[28] and Leith[29], furnish substantial evidence showing that strength in wheat is a heritable character retained even under very unfavorable environmental conditions of England and parts of India.

From the data reported in this bulletin it is evident that under the same conditions of environment some strains of wheat will retain a higher degree of hardness, a higher amount and better quality of gluten and produce a larger size of bread loaf than others. The logical deduction from this is that the individuality of the seed, the inherent characteristics of the wheat strain should enter as an inportant factor into the consideration of the chemical composition and bread making value of wheat.

The present data while covering only a very brief period are nevertheless of practical importance in their bearing upon the possibilities of growing good bread wheats in Northern Maine. Owing to the excellent adaptiveness of Aroostook soil and climate to the potato crop the area devoted to wheat in Aroostook is rather small and the growing of wheat in that section will be largely a problem of meeting primarily the local consumption, in other words, the growing of wheat in Aroostook will be concerned above all in raising good bread wheats for home baking. As to the question of raising good flour for home baking in Aroostook it is believed that our data offer a very satisfactory solution. We quote in this connection from the report of Dr. Hoffman, chief chemist of the Ward Baking Company, upon the baking test of our flours: "A number of the flours showed good quality glutens and made bread of very good quality. For home baking most of these flours are satisfactory and will produce a loaf with excellent eating qualities."

It is, of course, impossible, as yet, to say that the best pure lines so far selected represent the highest limit of baking strength under Aroostook conditions. Only results from a large number of selected strains tested for several years can give an answer to this question.

Until superior strains best adapted to Aroostook conditions are developed through selection or breeding the practical ques-

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[27]Biffen, R. H. Loc. cit. 1908.

[28]Howard, Albert, Leake, H. M. and Howard, G. L. C. Loc. cit.

[29]Leith, B. D. Loc. cit.

tion arises as to whether local or imported wheat should be used for seed. The best policy would be to secure local varieties of wheat of known performance in regard to yield and milling and baking quality. Such wheat varieties, however, are not generally available, and it has been a common practice with the Aroostook grower to import his wheat seed, usually from the Northwest. In importing wheat seed the practice of buying seed from mixed car lots of unknown varieties should be discouraged. Our experience with the Minnesota strains clearly indicates that in order to secure a satisfactory seed it is not enough to import hard wheats from the Northwestern Plains, for certain varieties and strains show a greater capacity for adaptation to humid regions than others. Thus the two strains of the Royalton wheat retained strength under Aroostook conditions yielding grain with a high percentage of protein, very good gluten with strong expansive qualities and good appearing loaves of good volume and very good quality. On the other hand the Marquis strain yielded a gluten with only medium quality and a flour lacking in strength. From this it is evident that an imported variety will first have to be tested for its capacity for retaining its strength under Aroostook conditions, and it is, therefore, essential not only to import seed from known varieties but that these varieties should be as free from admixtures as this is possible with commercial varieties. The more a variety approaches the condition of a pure strain the sooner and the more certain will its degree of adaptability to new conditions be determined.

While no definite recommendations can be made, as yet, as to the best variety for Aroostook conditions, our data furnish some information which may be of practical value. Under Aroostook conditions the Marquis strains did not make a good showing. They all yielded flour with short stiff gluten of only fair quality. Coupled with this rather low quality is a low yielding capacity. This is rather unfortunate as the early maturity of the Marquis would make this variety otherwise very desirable for Aroostook conditions.

The Preston strains are good yielders but only a few excel in quality though a number of them showed a high protein content. The growing of strong strains of the Preston group should be encouraged as they are well adapted to the conditions of Northern Maine.

The Canada Red strains (Ladoga type), while good yielders should be dropped on account of their low bread making quality. The Aroostook wheats are frequently mixed to a greater or less degree with these strains which probably lower the quality of the resultant flour.

The Red Fife and Bluestem varieties furnished the strongest strains yielding flour of very good to excellent baking quality. The Bluestem variety, however, is somewhat later than the Red Fife which is some drawback under Aroostook conditions. Its straw is perhaps not quite so strong as would be desirable and its hairy chaff tends to retain more moisture than the smooth chaffed varieties which may favor the attack by fungi and retard the maturing of the grain.

The Red Fife variety appears to be the best choice. The Red Fife strains yielded the strongest flour and have also a satisfactory yielding capacity. The Fife wheats have grown for a number of years in Aroostook County and are well adapted to the conditions of that section. From our experience and the results obtained in England, Canada and Australia it appears that the Red Fife wheats are characterized by a high capacity for adaptation and a strong tendency to retain their strength under unfavorable conditions of environment.

EXPLANATION OF PLATES.

The photographs on plates I, II, and III represent loaves of bread baked from flour of the pure lines of wheat grown at Aroostook Farm. The number under each loaf refers to the line of the wheat strain, except the first five loaves where the figure designates the accession number. Each loaf was baked from 300 grams of flour so that the size of these bread loaves is directly comparable. Note the variation in volume of loaves and texture of crumb.

PLATE 1.

180 182 185 186 217

2370 2373 2379 2383 2384

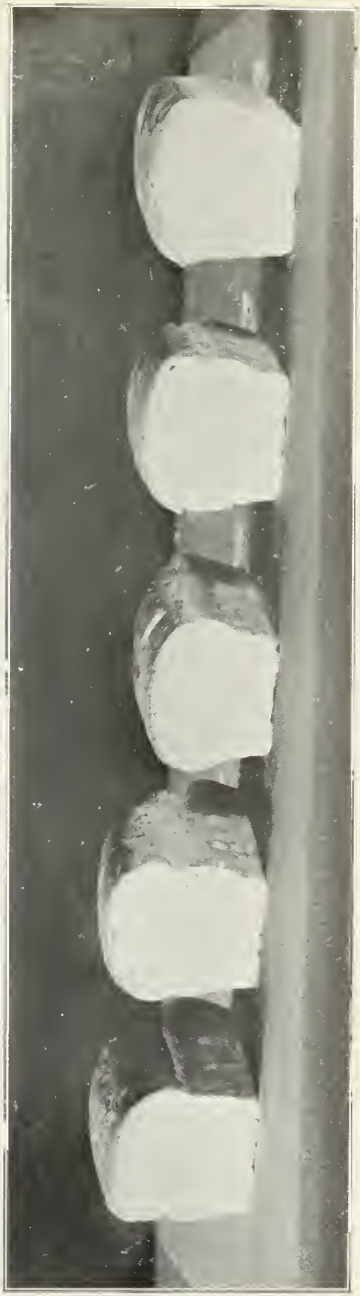

PLATE 2.

2396 2397 2398 2399 2400

2390 2391 2393 2394 2395

PLATE 3.